(12) UK Patent Application (19) GB (11) 2 099 717 A

(21) Application No 8203677
(22) Date of filing 9 Feb 1982
(30) Priority data
(31) 271756
(32) 9 Jun 1981
(33) United States of America (US)
(43) Application published 15 Dec 1982
(51) INT CL³ B01J 8/24
(52) Domestic classification B1F C1K
(56) Documents cited
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GB 1166675
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WOA 7900009
EPA 0031856
(58) Field of search B1F

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(54) Fluidized bed gasification ash separation and removal

(57) Method and apparatus for production of a combustible product gas from particulate coal in a fluidized bed system. A vertically positioned vessel includes an enlarged upper section and a smaller diameter cylindrical lower separator section, of diameter d, bounded at the bottom by a perforated or porous conical distribution plate (20) inclined at 7° to 15° with respect to horizontal; (the plate may also form an inverted cone). Coal is injected upwardly into or at the top of the separator section through tubular inlets (12) terminating a distance l above the distributor plate. The ratio l/d is less than 2.5. Fluidizing gas is injected into the separator section through the distributor plate, maintaining a fluidization velocity in the separator section of about 1.2 U_{mf} (where U_{mf} is the minimum fluidising velocity). Char and Ash particles are separated in the separator section, agglomerated ash being withdrawn from the bottom of the lower separator section and the char may be recycled to the combustion jet above the top of the tubular inlets.

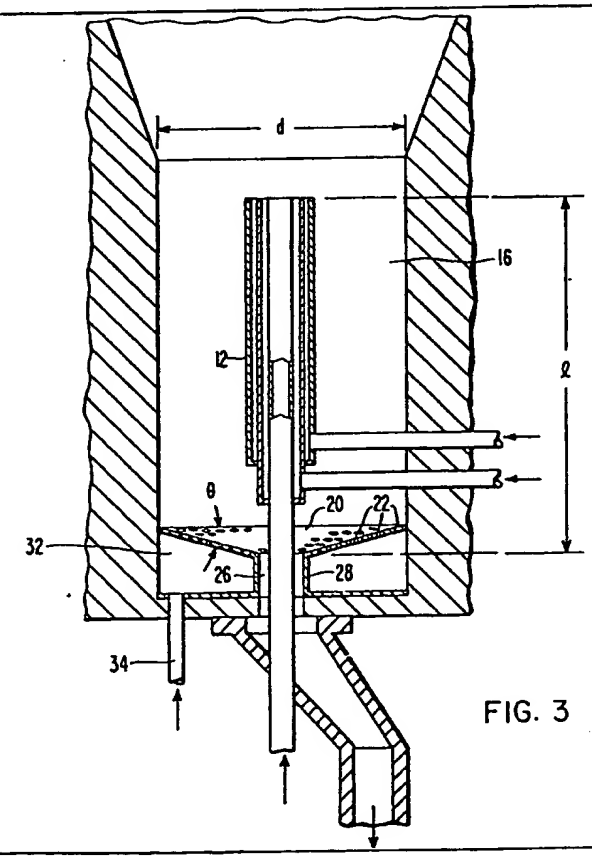

FIG. 3

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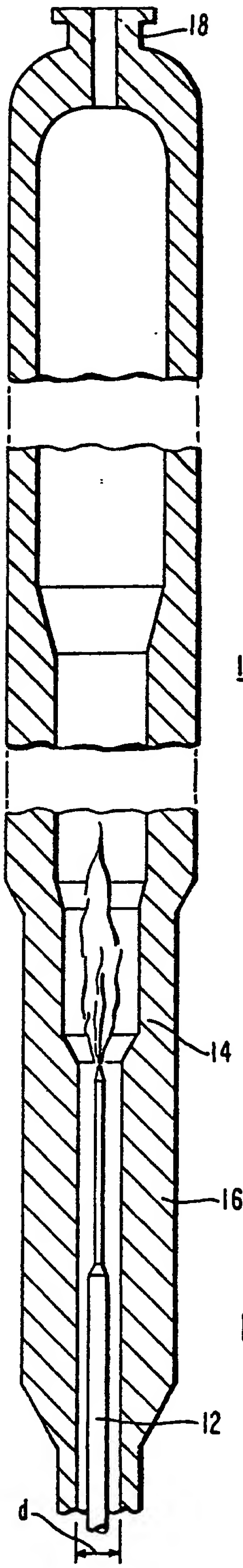
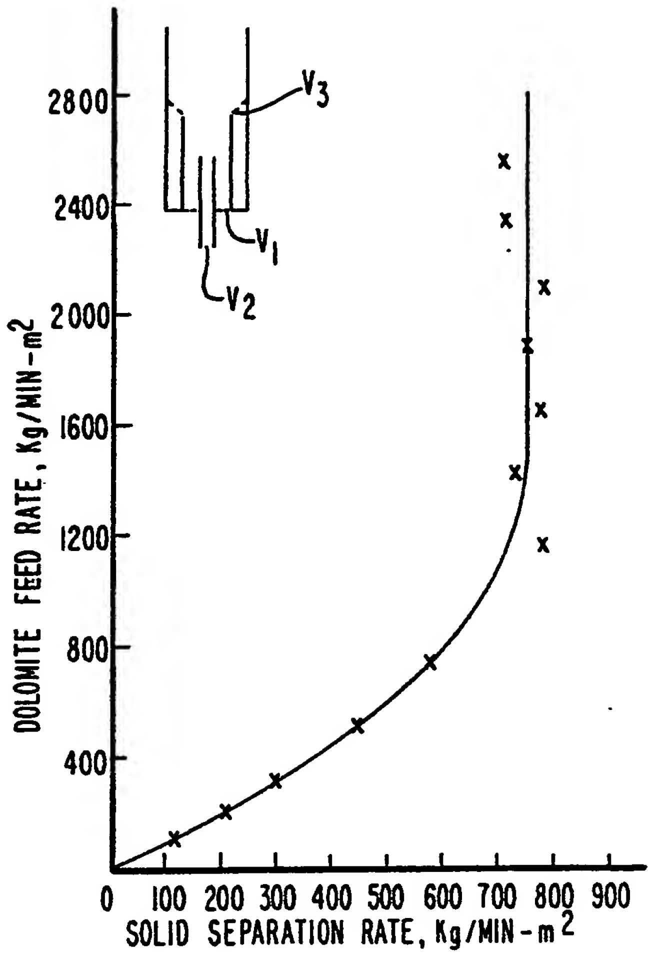

18
10
14
16
12
d

FIG. 1


DOLOMITE FEED RATE, Kg/MIN-m2
SOLID SEPARATION RATE, Kg/MIN-m2
0
100
200
300
400
500
600
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800
900
400
800
1200
1600
2000
2400
2800
V3
V1
V2

FIG. 6

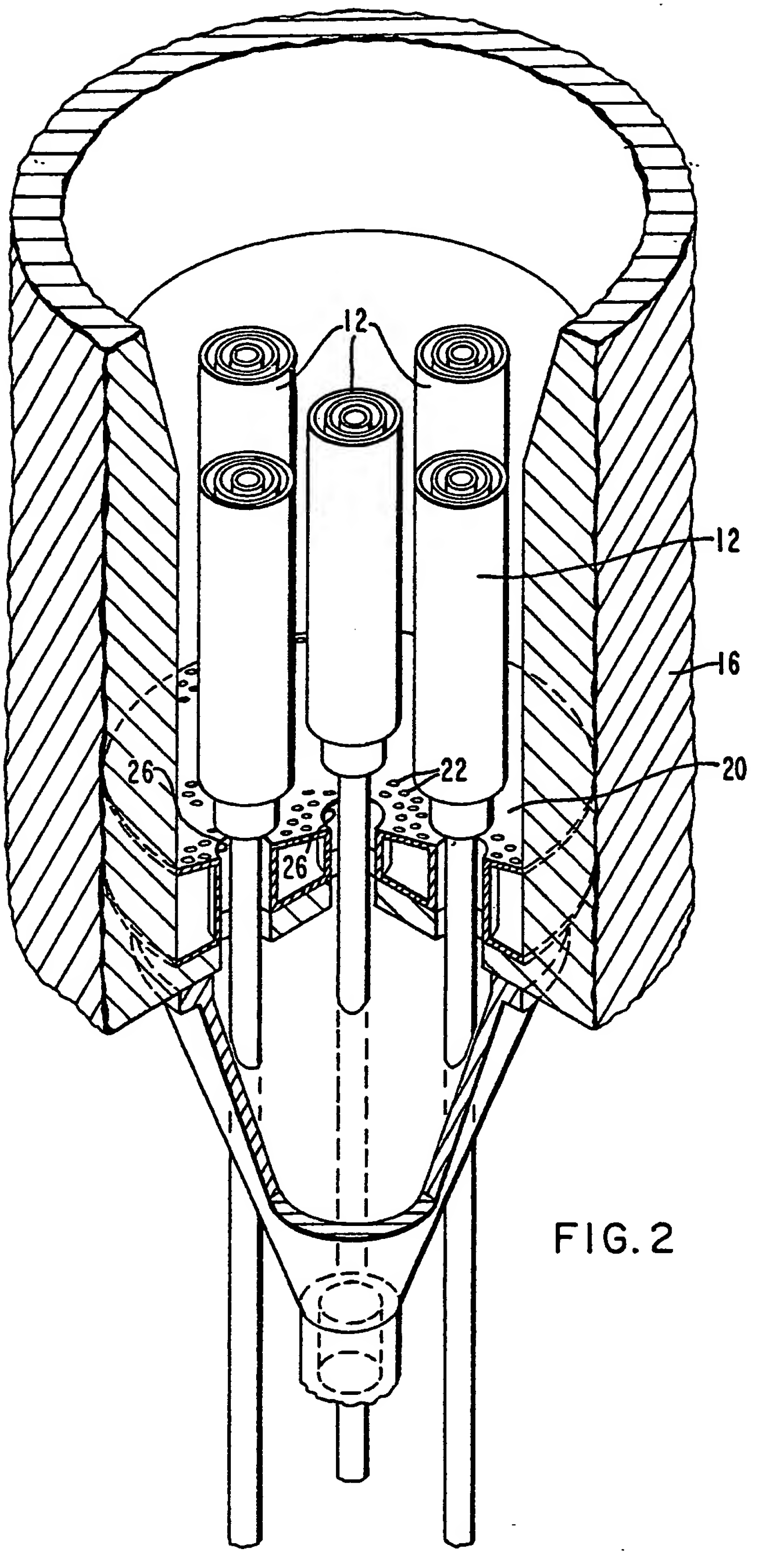

FIG. 2

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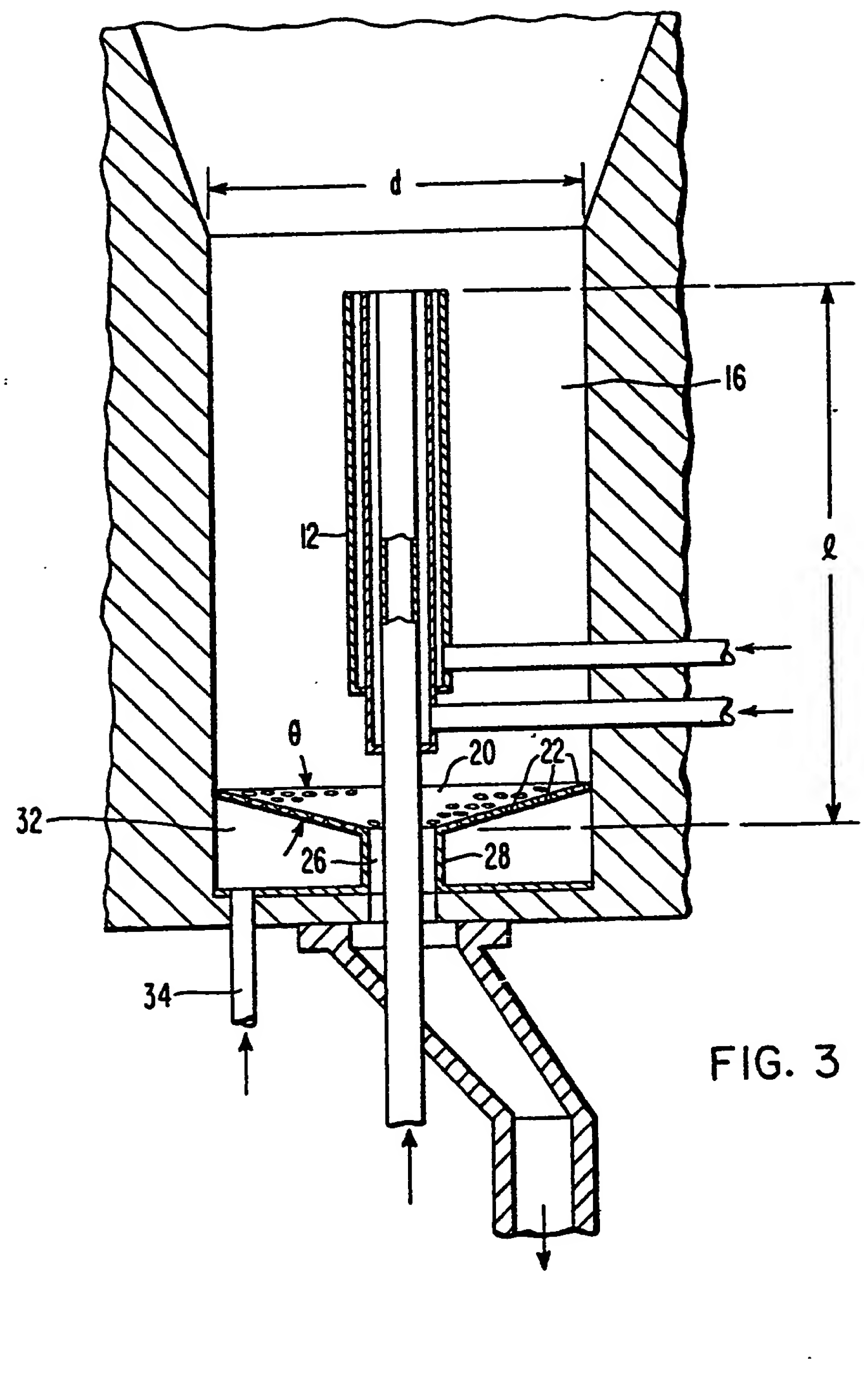

FIG. 3

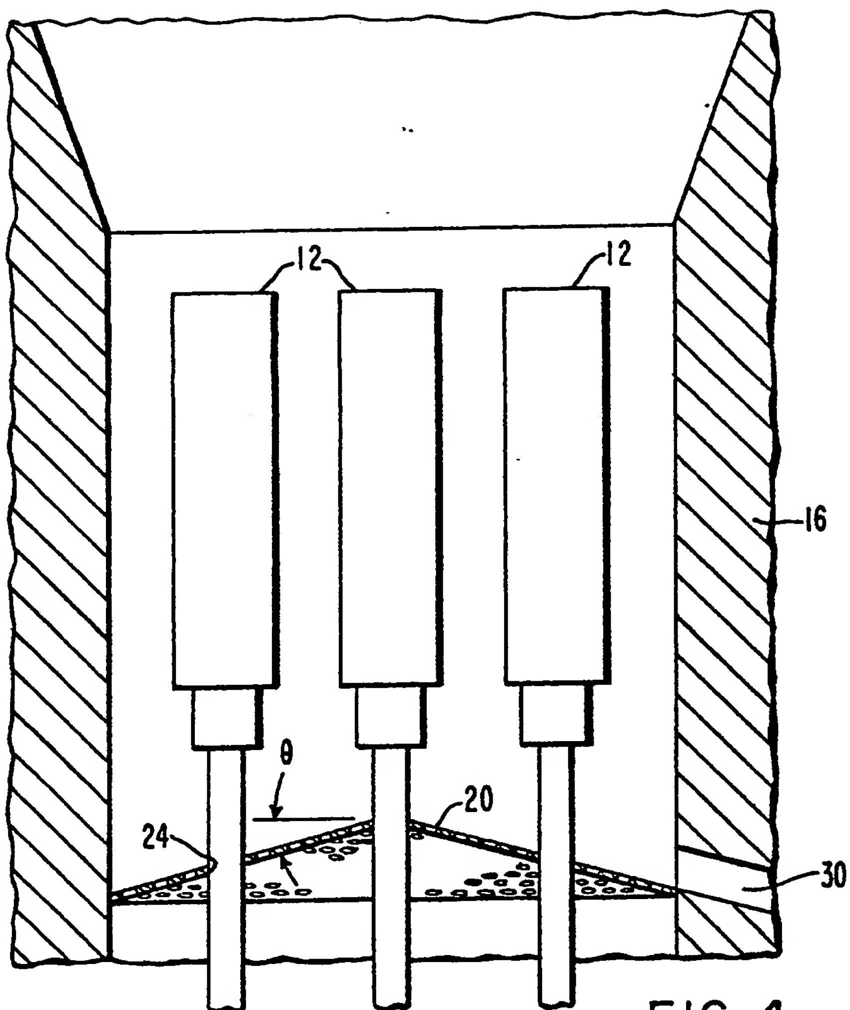

FIG. 4

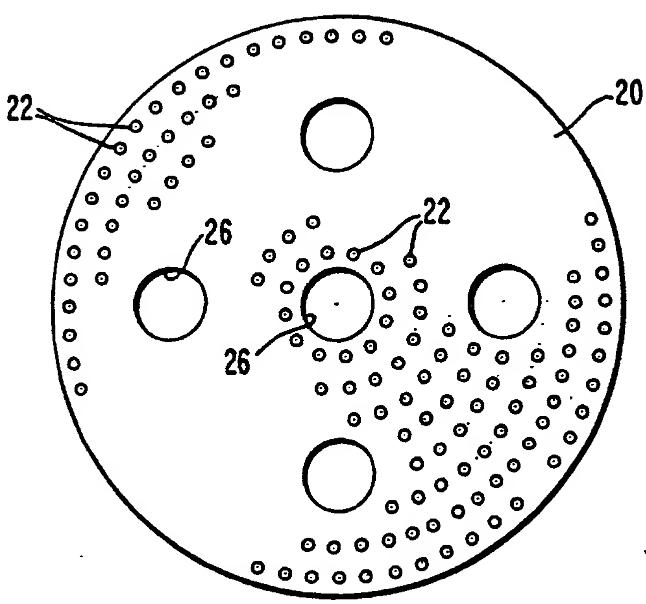

FIG. 5

SPECIFICATION

Fluidized bed gasification ash separation and removal

The invention disclosed herein was made or conceived in the course of, or under, a contract with the United States Government identified as No. EF-77-C-01-1514.

This invention relates to gasification of carbonaceous materials, and more particularly to method and apparatus for separation and removal of ash from fluidized bed gasification reactors.

In reactors for the gasification of carbonaceous materials, such as coal, a combustible product gas is produced, as well as solid waste products such as agglomerated ash. In the Process Development Unit (PDU) fluidized bed gasification reactor being operated for the United States Government, particulate coal is injected through the central one of a number of concentric tubes extending upwardly into the center of a vertical bed-containing pressure vessel. The vessel typically includes one or more upper sections of enlarged diameter relative to a lower section of smaller diameter, joined by a sloped transitional region. Fluidization occurs in the upper sections at a velocity greater than the commonly described minimum fluidization velocity (U_{mf}).

Fluidization and combustion support gases have been injected into the PDU in various manners, including vertically through the concentric tubes, radially from the concentric tubes, and through sparger rings disposed at selected elevations within the vessel. Other gasification reactors discharge a fluidizing gas into vertical vessels through perforated plates positioned near the bottom of the vessel.

In the PDU fluidized bed gasification reactor, feed particulated coal, in addition to producing a combustible product gas, intermediately forms char, and ultimately forms waste ash. The process takes place at temperatures in the range of 760°C to 1050°C. and above. The ash must be removed from the vessel, preferably continuously or by an on-line batch process, in order to maintain the process efficiently operational. It is desirable to remove only the ash as opposed to the incompletely reacted char, in order to maintain a high efficiency. It is also desirable to remove the ash at a low temperature, less than about 260°C, to minimize the impact of heat transfer on downstream components and to decrease heat loss. This can necessitate a long vessel with an elongated lower section through which downward movement of the dense ash takes place over an extended period of time, thus allowing sufficient cooling of the ash prior to removal from the vessel. It is, conversely, desirable to maintain gasification system components, including the containing vessel, at reasonable sizes for fabrication, structural integrity, cost and other purposes. An enlarged vessel also tends to require increased amounts of fluidization and combustion gases, thus detracting from system efficiency.

The fluidized bed gasification Process Devel pment Unit has been successfully perated at a coal throughput of approximat ly 15 tons p r hour f r air bl wn operation and 35 tons per hour for xygen blown operati n. Th unit has a single set of vertically positioned concentric injection tubes through which, in addition to particulate coal, various process mediums, such as recycled product gas, steam and oxygen, are injected. Additional fluidizing gas is injected through a sparger ring of circular cross section, concentrically disposed within the lower region of the gasifier vessel. In order to provide similar gasification systems of enlarged throughput, larger vessels will be required. It is also contemplated that larger concentric tubes, or multiple sets of tubes will be required. With such enlarged equipment, and particularly with multiple sets of concentric injection tubes, it has now been recognized that a single sparger will likely be insufficient to provide a relatively balanced distribution of fluidizing gases across the vessel cross section. This has not been previously recognized in the art. An imbalanced distribution can lead to channelling of the fluidizing gas flowing upwardly through the particulate matter. This can cause local slugging, excessive mixing, and local stagnation, as opposed to separation, of the char and ash particles.

It is therefore the principal object of the present invention to provide gasifiers of reasonably small size but capable of large throughput with complete gasification and combustion of coal or other carbonaceous feed material, and the capability to discharge product ash on-line and at a temperature below approximately 260°C.

With this object in view, the present invention resides in a coal gasification reactor of the fluidized-bed type comprising a vertically disposed vessel having an upper section of an inside diameter larger than the inside diameter d of a lower separator section, characterized in that, a conical perforated distribution plate (20) is disposed at the bottom of said separator section (16), the angle of said plate (20) relative to horizontal being greater than 7° and less than 15°, that means (34) are provided for injecting a fluidizing gas upwardly through said perforated distribution plate (20) and into said separator section so as to maintain a fluidization velocity of about 1.2 U_{mf} (minimum fluidization velocity) in said lower separator section, a plurality of solids injection tubes (12) extend vertically upward from said distributor plate (20) a length l, the ratio l/d being less than about 2.5, and that means (30) are provided for removing solids from atop said distributor plate. The combination of a flowing gas and the slope of the plate provide a small equivalent angle of repose such that ash particles can readily b removed from the plate through an nlarged opening at the center of the plate or through discharge outlets at the side of the plate.

Extending upwardly from the plate are multiple s ts of solid and gaseous injection tubes. Each set includes several concentric tubes, as well known, for injection of particulate coal, gasification,

combusti n and fluidization gases. The solid injection tubes, extend upwardly into the separati n section l ngth (l), and can extend to an el vation at th top f th separation section. By maintaining the ratio l/d in this structure at less than about 2.5, sufficient and evenly distributed fluidization gas flows through the perforations and upwardly through the separation section in a manner which facilitates separation of the char and ash and which avoids imbalanced pressure drop and associated channelling of the fluidizing gas within the separator section. The system avoids slugging operation in the separator section and associated intermixing of the char and ash which defeats the separation function, and can successfully operate with slugging occurring above the separator section. The system also provides sufficient residence time of ash particles within the separation section and sufficient heat transfer between the particles and the fluidizing gas to allow cooling of the ash particles to temperatures below about 260°C prior to removal from the reactor.

The invention will become more readily apparent from the following description of a preferred embodiment thereof shown, by way of example only, in the accompanying drawing, in which:

Figure 1 is an elevation view, in section, of a vessel for containment of a fluidized bed gasification process;

Figure 2 is a cut-away perspective view of the lower section of the containing vessel;

Figures 3 and 4 are simplified elevation views, in section, of the vessel and internal components for alternate embodiments;

Figure 5 is a plan view of a conical distribution plate; and

Figure 6 is a graphical representation of test data, plotting solid separation rate (kg/min-m^2, X-axis) versus feed rate (kg/min-m^2, Y-axis).

Referring now to Figure 1 there is shown a vertically oriented pressure vessel 10 for containing a fluidized bed gasification process. Process mediums, such as air or oxygen, recycle gas, steam, and particulate carbonaceous material, such as coal, are fed through concentric tubular inlets 12 into the vessel 10. The vessel includes several sections including one or more upper sections 14 of large inside diameter, and a lower separator section 16 of small inside diameter, d, relative to the upper sections. The vessel 10 can also include one or more transitional regions along the inside and outside diameters of the vessel.

The process mediums, upon injection, form a gasifying and combusting pressurized fluidized bed within th vessel 10, generally abov the top of the tubular inlets 12, where coal particles are intermediately devolatilized to char and a product gas, and ultimately the char is gasified and combusted to ash. The combustible product gas fr m th reaction is discharg d through an outlet 18, and agglomerated ash is discharged near the b ttom of the vessel. The process operates at a temperature in th range of 760°C t 1100°C, and above.

One, r pref rably a plurality of sets of c ncentric tubes, xtends upwardly from a distributor plate 20 to an elevation at or below the top of the lower separator section 16, as shown in Figures 2 through 4. The distributor plate 20 forms the bottom of the separator 16. The distributor plate 20 is perforated, including perforations 22 for passage of a fluidizing gas. The distributor plate also includes opening 24 through which pass one or more of the concentric tubular inlets 12. Each of the tubes of the inlets 12 can penetrate the distributor plate 20, as shown in Figure 2 or, as shown in Figure 3, some of the tubular inlets can enter the lower separator section 16 laterally.

The distributor plate 22 is generally conical, and preferably is oriented as an inverted cone as shown in Figure 3. It can also be oriented as an upright cone, as shown in Figure 4. With the inverted conical arrangement, product ash particles are withdrawn from the lower separator section 16 through one or more enlarged openings 26 at the lower elevation of the plate and an outlet conduit 28. The conduit 28 can include well known valve apparatus. With upright conical arrangement ash particles are withdrawn from the lower elevation of the plate 20, at the outer periphery, preferably through several outlets 30 about the periphery.

The perforations 22 are sized and configurated to allow upward passage therethrough of a fluidizing gas, such as recycled product gas, which enters a plenum 32 below the plate 20 through an inlet 34, and to restrict downward passage of the ash particles through the perforations. The fluidizing gas is injected at a fluidization velocity of about 1.2 U_{mf}, such that the lower separator section 16 operates under the mechanism commonly referred to as the minimum fluidization mechanism. Preferably the perforations 22, as shown in Figure 5, are circular of a 0.32 cm to 2.5 cm diameter. A metallic mesh can also be placed over the perforations. Alternatively, a sintered porous distribution plate of metal or ceramic materials can be utilized, for example, a plate comprised of sintered porous stainless steel or brass.

The ash withdrawal opening 26, if located at a position where no tubular inlets 12 penetrate the plate, is circular of a diameter of approximately six to eight inches. If the opening 26 is disposed about a concentric tube ˙2, the width of the annulus formed between the outer tube 12 and the ash withdrawal opening 26 is approximately six to eight inches.

The angle θ, the sl pe of the t p f the distributi n plate relative to horizontal, is between 7° and 30°, and preferably between 7° and 15°. It is desirable t minimize the angle in order to alleviate an uneven pressure differential acr ss the int rior volume of the lower separator section 16. A small angle minimizes the static head pressure dr p differential am ng th uppermost and

l w rmost perforations. A differ ntial causes a preferential flow path, or channelling through th lower pressure v lume f the separator and a fluidizing maldistribution, and poor separation of char and ash results. It is also desirable to increase the angle to assist in removal of ash particles on the distributor plate. Below a slope of 7°, even with fluid flowing through the perforations 22, ash particles tend to accumulate in position on the distributor plate and not migrate toward the outlet opening.

The lower separator section 16 is the region in which char and ash are separated, the char being upwardly recycled for further combustion, and the ash migrating downward for ultimate removal. A basic mechanism contributing to the separation is the ability of a rising bubble to carry a relatively low-density char particle upwardly in its wake, as opposed to a higher density ash particle. A mechanism which can defeat separation is slugging within the separator section. Slugging, the formation of a large gaseous bubble across the entire cross section of the separator 16, tends to push both ash and char particles upwardly. A slugging regime can, however, be avoided by maintaining the ratio l/d at less than about 2.5, where l is the distance between the distributor plate and the point within or near the top of the separator section at which raw carbonaceous material, such as coal, is discharged from a feed tube 12 into the free interior of the vessel 10, and where d is the internal diameter of the lower separator section.

The diameter d is preferably the minimum diameter which will prevent slugging in the separator section, while maintaining an appropriate l/d ratio, and will provide enough cross-sectional area for the char-ash separation. Additionally, in order to avoid a net accumulation of ash particles, the internal diameter of the separator section 16 is large enough to assure that the rate of char-ash separation is larger than the rate of ash agglomeration. Figure 6 graphically presents the results of experimentation on a system utilizing dolomite, simulating ash particles, and char fed into a fluidizing zone similar to the lower separator section 16. As shown, the maximum separation rate for the system, normalized on a cross-sectional area basis, is approximately 750 kg/min-m^2, regardless of the feed rate. The separation rate is heavily dependent upon the relative concentration of the two feed materials and their relative density and size ratios. The test unit operated at a pressure of 15.5 kPa and ambient temperature. The injection rates were $V_1 = 0.24$ m/sec, $V_2 = 25.3$ m/sec, and $V_3 = 0.27$ m/sec, where V_1, V_2 and V_3 are injected as shown in the sketch f the test apparatus in the upp r left corner of Figure 6, and correspond respectively to (V_1) the fluidizing gas injection through the distributor plate 20 (V_2) th injection of solids in a transport gas through the tubular inlets 12, and (V_3) a gaseous injection through a truncated conical grid above the lower separator section 16.

In addition t limiting slugging, the separator section 16 preferably is of sufficient height t provide cooling of the ash particl s, prior to removal from the vessel 10, to a desirable t mperatur ; preferably less than 260°C.

The top of the concentric tubular inlets 12 is disposed at the top of or within the lower separator section 16. It is desirable to minimize the length l to shorten the overall height of the vessel 10 and to improve solids recirculation for gasification and combustion, since particle velocity is greater in the smaller, lower section 16 cross-sectional area. Where the top of the tubular inlets 12 is within the separator section, sufficient penetration of the combustion jet into the section of the vessel 10 above the separator section 16 exists to ensure that either the combustion jet penetrates into the gasification region above the separator section or the bubble size generated above the combustion jet within the separator section is smaller than the char-ash separator section 16 inside diameter, so as to avoid slugging in the separator section. Increased bubble size above the separator section is acceptable.

An exemplary vessel 10 including a char-ash separator section 16 approximately three feet in diameter and five feet high, with concentric tubes extending between three and five feet upwardly into the separator section meets the described relationships. Table I identifies other system parameters:

Ash removal rate	2250 kg/hr
Superficial gas velocity in separator section	45—76 cm/sec
Mean ash particle size	1650 microns
Ash particle density	1.6 kg/dm^3
Gasification bed temperature	985°C—1070°C
Ash discharge temperature	260°C
Air jet velocity from tubular inlets	18—37 cm/sec
Diameter of outer tubular inlet	40.6 cm
Separator bed voidage	0.48
Inverted distributor cone angle	15°
Perforation diameter	3.2 mm
Number of perforati ns	194

For the exemplary system the combusti n jet penetration is up to 1.52 m and the maximum bubble size is 1 m at an levation within th gasifier b d. However, b caus of the longat d jet pen tration th separator s cti n diameter of

0.9 m is sufficient to alleviate slugging interference with the separation function since large bubbles appear only in the gasifier section.

A fluidized bed gasification system operating with a lower separation section of the minimum fluidization type, as disclosed, will provide efficient separation of char and ash, alleviate slugging in the separator section, and provide separation of char and ash at a rate compatible with the ash agglomeration rate. Additionally, ash particles will have sufficient residence time in the separator section in contact with a cool gas to assure discharge from the containing vessel at acceptable temperatures.

CLAIMS

1. A coal gasification reactor of the fluidized-bed type comprising a vertically disposed vessel having an upper section of an inside diameter larger than the inside diameter d of a lower separator section, characterized in that a conical perforated distribution plate (20) is disposed at the bottom of said separator section (16), the angle of said plate (20) relative to horizontal being greater than 7° and less than 15°, that means (34) are provided for injecting a fluidizing gas upwardly through said perforated distribution plate (20) and into said separator section so as to maintain a fluidization velocity of about 1.2 U_{mf} (minimum fluidization velocity) in said lower separator section, a plurality of solids injection tubes (12) xt nd v rtically upward from said distributor plat (20) a length l, the ratio l/d being less than about 2.5, and that means (30) ar provided for removing solids fr m atop said distribution plate (20).

2. A reactor as claimed in claim 1, characterized in that said distribution plate (20) consists of sintered porous stainless steel.

3. A reactor as claimed in claim 1, characterized in that distribution plate (20) consists of sintered porous brass.

4. The reactor of claim 1, characterized in that said solids injection tubes (12) extend upwardly from said distribution plate (20) and terminate within said separator section (16).

5. A method of operating a gasification reactor as claimed in any of claims 1 to 4, wherein char and ultimately ash and a combustible product gas are formed, characterized in that, particulate carbonaceous material is injected upwardly into said vessel at an elevation below the top of said lower section, gasification and combustion support gas are injected into said lower section such that a combustion jet extends upwardly above said lower section and into said enlarged upper section, fluidizing gas is injected upwardly into said lower section at a rate so as to maintain a fluidization velocity in said lower section of about 1.2 U_{mf}; and the ash is removed from the bottom of said lower section.

Printed for Her Majesty's Stationery Office by the Courier Press, Leamington Spa, 1982. Published by the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained